ANALOG COMPRESSION OF GPS C/A SIGNAL TO AUDIO BANDWIDTH

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U. S. C. § 119(e) of United States Provisional

5   Patent Application No. 60/227,671, filed August 24, 2000, entitled "ANALOG COMPRESSION

OF GPS C/A SIGNAL TO AUDIO BANDWIDTH," by Charles P. Norman, which application is

incorporated by reference herein.

10   ## BACKGROUND OF THE INVENTION

1.   Field of the Invention.

The present invention relates in general to Global Positioning System (GPS) signals, and in

particular to a method and apparatus for analog compression of GPS clear/acquisition (C/A) signals

to audio bandwidths.

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2.   Description of the Related Art.

Currently, there exists a position determining system, referred to as the NAVSTAR Global

Positioning System (GPS), wherein a constellation of 24 orbiting satellites transmit pseudo-random

ranging signals from which users with appropriate equipment can obtain three-dimensional location,

20   velocity and timing information anywhere on or near the surface of the Earth. The longitude,

latitude and altitude of any point close to Earth, with respect to the center of the Earth, will be

calculated by determining propagation times of electromagnetic signals from one or more of the

satellites to the point in question.

A signal about a single center frequency from one or more of the visible satellites will be

25   received by a user terminal at a point close to Earth to measure propagation times of the

electromagnetic signals transmitted by the satellites. The satellites from which the signals originate are identified by modulating the signal transmitted from each satellite with pseudo-random coded signals. The GPS System will operate in two simultaneous modes. In one mode, referred to as the clear/acquisition (C/A) mode, the pseudo-random noise (PN) signal is a Gold code sequence that is

5   repeated once every millisecond to enable the position of the receiver responsive to the signals transmitted from one or more of the satellites to be determined to an accuracy better than 100 meters.

E911 requires capability to determine the location of a handset. The location information is required to be passed through a narrow band communication channel. A compressed C/A code can

10   be sent over any cellular communications channel, enabling location of the handset by the receiver. Further, mobile devices require low power consumption, and with compressed messages, lower transmitter and receiver power is used.

It can be seen, then, that there is a need in the art for techniques to compress the C/A code. It can also be seen, then, that there is a need in the art for compressing the C/A code in order to use

15   the C/A code with other remote GPS receiver components. It can also be seen that there is a need in the art to provide the compressed C/A code in a relatively inexpensive manner. It can also be seen that there is an need in the art for low power GPS receivers.

SUMMARY OF THE INVENTION

To minimize the limitations in the prior art, and to minimize other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses a method and apparatus for using analog circuitry to compress the GPS C/A signal to an audio bandwidth.

A method for compressing a Global Positioning System (GPS) signal in accordance with the present invention comprises removing a carrier component of the GPS signal, matching a comb filter to the GPS signal to obtain a first output comprising filter lines, and frequency shifting the filter lines in the first output to produce a compressed GPS signal.

It is an object of the present invention to provide techniques to compress the C/A code. It is another object of the present invention to provide methods and devices to compress the C/A code in order to use the C/A code with other remote GPS receiver components. It is another object of the present invention to provide methods and devices to compress the C/A code in a relatively inexpensive manner. It is also an object of the present invention to provide low power GPS receivers.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding

parts throughout:

FIG. 1 illustrates a system in accordance with the present invention; and

5   FIGs . 2A-2H illustrates the operation of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

In the following description of the preferred embodiment, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other

5   embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Overview

Any periodic signal has a Fourier series consisting of frequencies that are integer multiples

10   of the repetition frequency. The C/A code repeats every millisecond, thus the signal power is limited to frequencies that are integer multiples of 1 kHz.

The code is modulated onto the L1 carrier frequency. This signal is then received by the user and will have a Doppler shift. The receiver can remove the L1 carrier, leaving only the C/A code and Doppler. In order to filter out the noise between the 1 kHz frequencies an assist signal

15   needs to be provided that places a satellites Doppler at an integer multiple of 1 kHz. The periodicity of the C/A signal limits the bandwidth of this assist signal to 1 kHz.

The C/A code is modulated with telemetry data bits at a 50 Hz rate. To maintain the periodicity of the signal the telemetry data bits need to be removed from the signal. Modulating the previously described assist signal with the data bits will remove the data modulation. This increases

20   the bandwidth of the assist signal to 1100 Hz.

The C/A code repeats 20 times for every telemetry data bit. This repetition places the signal power in spectral lines spaced 1 kHz apart. The signal can be compressed without any loss of signal by transforming these 20 repetitions to the frequency domain and zeroing the frequency bins that

-6-

have no signal. The remaining bins can be transformed back to the time domain with the bandwidth reduced by a factor of 20. The compression is the same as the number of repetitions used. If the 50 Hz telemetry data bit transitions are removed then more than 20 repetitions may be used. The factor limiting the number of repetitions that can be used now becomes the users motion. If the user motion is limited to 0.5 g acceleration then the bandwidth may be reduced by more than a factor of 100 without loss of signal.

Additional methods of bandwidth compression are possible but may result in signal loss. One method is to eliminate transmission of some of the spectral lines. Since the signal level in each line varies, it is possible to eliminate the lines with the least power to minimize the signal loss. Another method of bandwidth compression is to overlap the output bands. The portion of the output bands that overlap will have increased noise density, causing a reduction in signal to noise ratio. No loss occurs when each line is band limited such that the noise power in the band around each line doesn't overlap the next line's band.

Example System

FIG. 1 illustrates a system in accordance with the present invention.

System 100 comprises a remote receiver 102 that has a radio link 104 to a base station 106. The radio link 104 can provide a common frequency reference to both remote receiver 102 and base station 106, so the system 100 will not be concerned with user clock offsets. The base station 106 can also provide an assist signal to remote receiver 102 via radio link 104 to remove telemetry data and Doppler due to satellite motion.

Remote receiver 102 comprises a GPS antenna 108 that is able to receive signals from GPS satellites. The GPS antenna 108 can be the same antenna or a different antenna than that used to

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provide radio link 104. GPS signals that are received at GPS antenna 108 are put through mixer

110, where they are mixed with L1 signal 112 to remove the L1 carrier. The resultant signal 113

contains the GPS data in a spread spectrum format. Signal 113 is then mixed with the receive signal

114 at mixer 116, and the resultant signal 118 is filtered in a 1 kHz comb filter 120.

5   The output 122 of comb filter 120 is mixed with outputs from frequency generators 124 at

mixers 126. The outputs from mixers 126 are filtered through a bandpass filter signal combiner 128,

and filtered output 130 is duplexed through duplexer 132 for transmission on radio link 104 to base

station 106.

10   Operation of the Invention

          FIGS. 2A-2H illustrate the operation of the invention.

          In the remote unit 104 of the present invention, the bandwidth of signal that remote unit

104 must transmit from remote unit 104 to base station 106 is typically about 1 MHz when the

signal is not compressed. The present invention reduces the bandwidth of the signal that needs to

15   be transmitted to base station 106 by compressing the GPS signals to a bandwidth of less than 2

kHz.

          Spectrum 112, shown in FIG. 2A, is essentially noise with embedded GPS signals. Signal

114, shown in FIG. 2B, is used to shift comb filter 120 by a fraction of a kHz to line the comb filter

up with expected signal peaks, or to adjust comb filter 120 to a new position to acquire and/or track

20   a different satellite. The spectrum shown in FIG. 2C shows the spectrum after frequency shifting

the signal to line up the signal spectral lines with the comb filter lines. 50 Hz data 130 is present in

the signal. FIG. 2D shows signal 122 as a series of lines, which results from mixing signals 112 and

position of remote receiver 102 back to remote receiver 102 via radio link 104 for use by remote receiver 102 in location services, dead reckoning, E911 situations, or other areas or services where remote receiver 102 would need a position calculation.

5   The present invention reduces the complexity of the circuitry required at a remote receiver 102. There is no longer a "GPS receiver" located at remote receiver 102. Instead, there is an apparatus for removing the L1 carrier and circuitry for sending compressed GPS signals to a base station for calculation of a position of the remote receiver 102. The present invention thus allows remote receivers 102, such as cellular telephones, Personal Communications System (PCS) communication devices, Personal Data Assistant (PDA) devices, mobile computers, and other

10 mobile devices to have a small, lightweight, low power addition and still have access to GPS positioning technology. Further, since the bandwidth of the signal 130 is so small, an identification (ID) signal can be attached to the signal 130 at the remote receiver, such as a Mobile Identification Number/Electronic Serial Number (MIN/ESN), such that the base station 106 can determine which remote receiver 102 the base station 106 is calculating a position for. Such data is useful for

15 statistical purposes, as well as a fee-for-service purpose of the base station 106 or wireless carrier that is providing position calculation services as described by the present invention.

    The present invention envisions that an all-analog remote device, which is compatible with the remainder of the GPS receiver and processing circuitry, can transform the C/A signal such that the C/A signal can be transmitted over any audio bandwidth communication link. The transformed

20 C/A signal can then be processed, either locally or remotely, to obtain the location of the remote device. Further, the present invention envisions that an all-digital device can perform the same functions as described in the analog system presented herein.

Although the above system has been presented as an example, other systems are possible

within the scope of the present invention that can be optimized for one or more design variables,

e.g., low power, for the required output bandwidth, vehicle dynamics, sensitivity, or other design

goals.

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Simulation

A digital simulation was performed by creating a sequence of sampled C/A code plus noise.

The compression was simplified by filtering and frequency shifting of the sample sequence as

follows:

```
10   void filterUpdate(complexType sampleData,
       complexType filterData[],
       long rotationIndex,
       long sampleSize)
     {
15     long i;
       long thisIndex = 0;
       long rotationStep = (rotationIndex * TABLE_SIZE /
                           sampleSize) % TABLE_SIZE;
     #define alpha  1.0
20   #define beta 1.0

       for (i = 0; i < sampleSize; i++)
       {
           filterData[i] = complexSum(
25     complexProduct(fromFloat(beta, 0.0),filterData[i]),
       complexProduct(fromFloat(alpha, 0.0),
       complexRotation(sampleData, thisIndex)));

         thisIndex -= rotationStep;
30       if (thisIndex < 0)
           thisIndex += TABLE_SIZE;
       }

     }
35
     complexType Compress(complexType filterData[],
       long compression,
```

```
                long rotationIndex,
                long sampleSize)
              {
                long i;
 5              long thisIndex = 0;
                long rotationStep = (rotationIndex * TABLE_SIZE /
                   sampleSize) % TABLE_SIZE;
                complexType retval = complexZero;

10              for (i = 0; i < sampleSize; i += compression)
                {
                    retval = complexSum(retval,
                          complexRotation(filterData[i], thisIndex));
                    thisIndex += rotationStep;
15              if (thisIndex >= TABLE_SIZE)
                    thisIndex -= TABLE_SIZE;
                }

                retval.I /= sampleSize / compression;
20              retval.Q /= sampleSize / compression;

                return retval;
              }
```

25   Part of the main program to illustrate the present invention is:

```
     for (i = 0; i < TABLE_SIZE; i++)
     {
        filterUpdate(signal[i],
                    filterData,
                    i,
30                  1023 * COMPRESSION_FACTOR);
        SigComp[i] = Compress(filterData,
                    COMPRESSION_FACTOR,
                    i,
35                  1023 * COMPRESSION_FACTOR);
     }
```

There are several ways to process the compressed samples. The most efficient would be to

sub sample at a sample rate that is twice the compressed bandwidth. The simulation sample rate was

kept the same for simplicity. The compressed signal was transformed to the frequency domain and

then decompressed by shifting the frequency bins with the following:

```
        void deCompress(complexType compressFreq[], complexType deCompressFreq[],long
 5  compression, long sampleSize)
            {
              long i;
              long thisIndex = 0;

10            for (i = 0; i < sampleSize; i++)
              {
                if ( i % compression)
                  deCompressFreq[i] = complexZero;
                else
15              {
                  deCompressFreq[i] = compressFreq[thisIndex];
                  thisIndex++;
                }
              }
20          }
```

The decompressed samples are transformed back to the time domain and the output signal is

compared to the input signal.

The simulation verifies that the input SNR is the same as the output SNR when all 1023

25 frequency lines are preserved and the compression does not overlap noise bandwidth about each

frequency.

Conclusion

        Although the description of the present invention herein describes specific embodiments of

30 the present invention, the scope of the present invention includes other embodiments of the present

invention not described herein.

In summary, the present invention describes systems, methods and apparatuses for reducing or eliminating the auto-correlation or cross-correlation events that occur during weak signal conditions. The devices in accordance with the present invention also provide the ability to correct the auto- or cross-correlation event to allow the GPS receiver to lock onto the proper signal.

A method for compressing a Global Positioning System (GPS) signal in accordance with the present invention comprises removing a carrier component of the GPS signal, matching a comb filter to the GPS signal to obtain a first output comprising filter lines, and frequency shifting the filter lines in the first output to produce a compressed GPS signal.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention not be limited by this detailed description, but by the claims appended hereto.